

EFFECTIVE VISCOSITY OF PAM SOLUTIONS THROUGH POROUS MEDIA

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The effectiveness of high molecular weight polyacrylamide polymers in reducing erosion from furrow irrigated fields has been well documented in this conference. The application of polymers in irrigation water may also contribute to higher infiltration rates. This paper will explore the mechanisms by which polymers in solution can alter infiltration rates. The understanding of the mechanisms will then be used to develop some basic management decisions.

Darcy's law describes the rate of water flow through soil. The water flow rate is equal to the hydraulic conductivity, K , times the hydraulic head gradient. The value of K depends on both the soil pore sizes and viscosity of the water. There is a proportional inverse relationship between K and viscosity.

Adding polymer to water may affect infiltration rate by modifying the pore size distribution of the soil and the viscosity of the water. When compared to untreated water, the polymer solution will, under most circumstances promote higher pore sizes. The relative effect of the polymer depends on the susceptibility of the soil to disperse in untreated water, which is dependent on soil type and chemical composition of the irrigation water. Addition of polymer to water can increase the viscosity of the solution which lowers the infiltration rate. Therefore, the effectiveness of a polymer in increasing infiltration rate is dependent upon the relative beneficial effect of promoting higher pore sizes and the negative effect of increased solution viscosity.

The results of many experiments done in my laboratory with polymers could have been affected by the solution viscosity. A crude technique was used to determine whether the polymer was causing a great change

in the solution viscosity. The time required for a 10-mL pipette to empty under free flow was measured for water and various polymer concentrations. The time for discharge was assumed to be proportional to viscosity. There was only a very slight increase in apparent solution viscosity measured by pipette up to a polymer concentration of 400 mg/L. Since most experiments were conducted with polymer solutions of much lower concentrations, it was assumed from this crude technique that the deviations of viscosity of the polymer solution was negligibly different from water. Nevertheless, observations during experimentation suggested that the polymer solution flow through soils was slower than might be expected based on the soil pore size distributions. These observations prompted a further investigation on the effects of polymer on solution viscosity.

The solution viscosities were measured by two types of commercial viscometers: the Fisher Kinematic Viscometer tubes and Brookfield LB Rheostat viscometer with UL adapter. The Brookfield viscometer measures the torque required to rotate an immersed element in the fluid. There was a slight difference in the viscosity measured by the two commercial viscometers. But more significantly, the viscosity measured by the commercial viscometers was considerably higher than determined from the pipette. The effect of polymer on solution viscosity could be determined in porous media by measuring the hydraulic conductivity. The value of K is dependent upon both the pore size of the media and viscosity of the water. The term permeability, k , is a property of the porous media alone and independent of the fluid. The relationship between K and k is

$$K = k\rho\zeta/\eta \quad [1]$$

where η is the fluid viscosity, ρ is the fluid density and ζ is the gravitational constant. Inasmuch as the water density is not significantly

changed by addition of polymer, any change in K by the addition of polymer would be the result of a change in viscosity if the pore sizes remain constant.

From equation 1, the ratio of the hydraulic conductivity of water, K_w , to that of a polymer solution, K_p , for a given sand size (constant k) would be

$$K_w/K_p = \rho_w\eta_p/\rho_p\eta \quad [2]$$

the relative viscosity, ρ_p , can be calculated from the relative hydraulic conductivities and assuming $\rho_w = \rho_p$:

$$\eta_p/\eta_w = K_w/K_p \quad [3]$$

A study was conducted Malik and Letey (1992) to determine the relative viscosity of three polymers at various polymer concentrations. Quartz sand was selected as a porous media so that the polymer could not alter the physical matrix. Two size fractions of the sand were used and will be referred to as fine (radius less than 0.5 mm) and coarse (radius between 0.5 and 1.0 mm). One hundred grams of sand were packed in columns which were 2.8 cm diameter and 20 cm long, on three layers of cheese cloth held to the bottom of the column by a rubber band. Three high molecular weight polymers at three levels of anionic charge were used in the study. The polyacrylamide was made anionic by substitution of NH_2 by OH at 2, 21 and 40% substitution. These polymers are labeled 2J, 21J and 40J to represent the percentage of substitution. More detailed description of these polymers is given by Aly and Letey (1988). The 21J polymer has molecular characteristics comparable to the polymers which have been extensively used in the field to control erosion. Each polymer was dissolved in tap water from the city of Riverside, California, to concentrations of 0, 25, 50, 100, 200, 300 and 400 mg/L.

Each column packed with sand was saturated from below by slowly immersing it into the solution until it had free standing solution above the sand. The column was then removed from

Figure 1. Hydraulic conductivity as a function of polymer concentration in coarse sand.

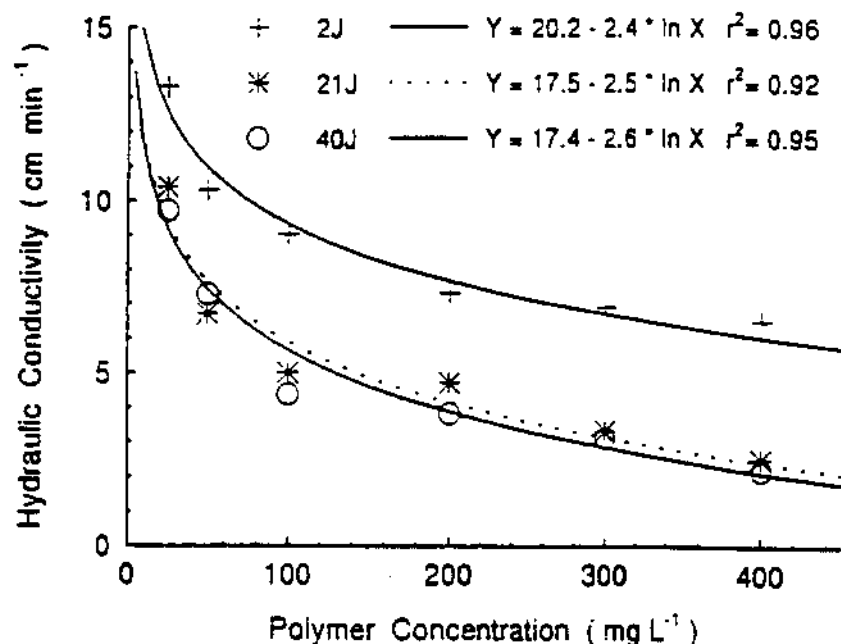
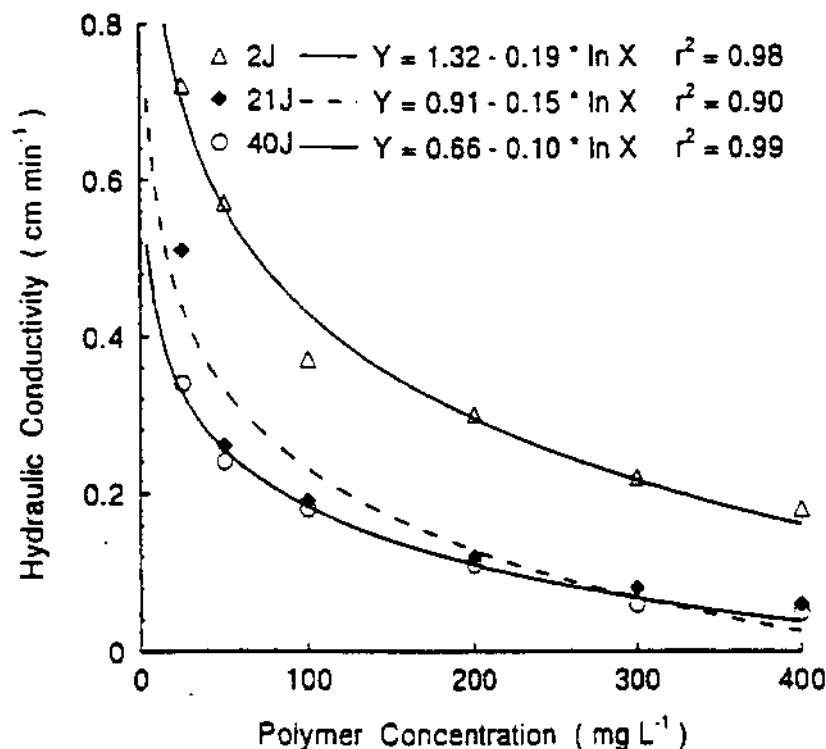


Figure 2. Hydraulic conductivity as a function of polymer concentration in fine sand.



the solution and a 2-cm head (relative to the sand surface) was maintained without the sand becoming unsaturated at the surface. The solution was allowed to flow through the sand. The steady-state flow rate was measured and the hydraulic conductivity was calculated.

The K values of the polymer solutions are plotted as a function of polymer concentration in coarse and fine sand in figures 1 and 2, respectively.

The best-fit curves are drawn for visual convenience and are represented by the equations on the figures. The r^2 values identify how well the curves depict the measured data. The K values decreased with increasing polymer concentration in each case. For tap water, the hydraulic conductivities of coarse and fine sand were 13.3 and 0.75 cm/min, respectively. Inasmuch as a solution density and pore sizes were the same in each case, the

value of K_w relative to K_s could be used to calculate the relative viscosity's by equation 3. The relative viscosities of the polymer solution is plotted as a function of polymer concentration for the three polymers in fine and coarse sands in figure 3. The viscosity values are in the order of $40 J > 21 J > 2 J$. An approximate linear relationship between relative viscosity and polymer concentration was observed. Noteworthy is the fact that the relative viscosity of a given polymer solution is much higher in the fine sand than in the coarse sand. This observation indicates that equation 1 is not valid for these solutions.

According to equation 1, the relative viscosity of a given polymer concentration should be independent of pore size. The data presented in figure 3 clearly and unambiguously demonstrate that this is not the case. Also, the viscosity as determined by hydraulic conductivity through the porous media is much higher than the viscosities measured by the commercial viscometers. Clearly, there are factors related to solution flowing through porous media which causes the polymer solutions to behave as if they were more viscous.

A test was conducted where water and the 200 mg/L 21J solution were alternately allowed to flow through the column. The water in polymer solution flow rates were not affected by alternating applications. The water flow rate was always higher than the polymer solution flow rate and not affected by previous polymer application.

The results of this experiment suggest that the effective viscosity of polymer solutions when caused to flow through porous medium are higher than would be anticipated by standard viscosity measurements. Furthermore, the relative viscosity is dependent upon the pore size. From a practical field condition, a number of significant questions remain unanswered.

First, the polymer concentrations used in the study were much higher than those now being recommended for field application to reduce erosion. Secondly, the pore sizes in the soil are much smaller than the fine sand which could potentially enhance the

effective viscosity beyond those which were measured in the study.

We have initiated some recent studies using polymer concentrations of 10 mg/L and less, consistent with recommended treatments in the field. We have also attempted to investigate smaller pore sizes, however we are constrained with the problem that the real fine soil particulates can be flocculated by the polymer and therefore confound the results.

The results are preliminary, however, the hydraulic conductivity successively decreased with increasing polymer concentrations from 0 to 10 mg/L. The hydraulic conductivity of the 10 mg/L solution was approximately one-half of that of the untreated water (Table 1). Thus, the polymer affects the viscosity of solution even at the low concentrations.

The increased effect of viscosity is not necessarily bad. Usually the infiltration rate of soils is quite high after cultivation and one of the problems with furrow irrigation is that there is significant water infiltrating in the upper end of the field as compared to the lower end of the field. Increasing the effective viscosity of the solution therefore decreasing infiltration rate would cause water to advance down the furrow more rapidly thus smoothing out the uniformity of water application. Low infiltration rates usually are a greater problem after the first irrigation because of the low permeable layer deposited on the furrow bottom by dispersed soil particulates. Treatment with the polymer decreases this effect and therefore should have a positive affect in subsequent irrigations. If the subsequent irrigations are done with untreated water, then the viscosity is no longer a problem.

Thus, one strategy is to make sure the polymer treatment during the first irrigation after cultivation is very effective in causing soil flocculation and preventing soil dispersion. Subsequent irrigations might be conducted with untreated water taking advantage of the enhanced porous media caused by the initial polymer treatment but not impacted by low viscosity of a polymer solution.

Figure 3. The viscosity of various polymer solutions relative to water in fine and coarse sands.

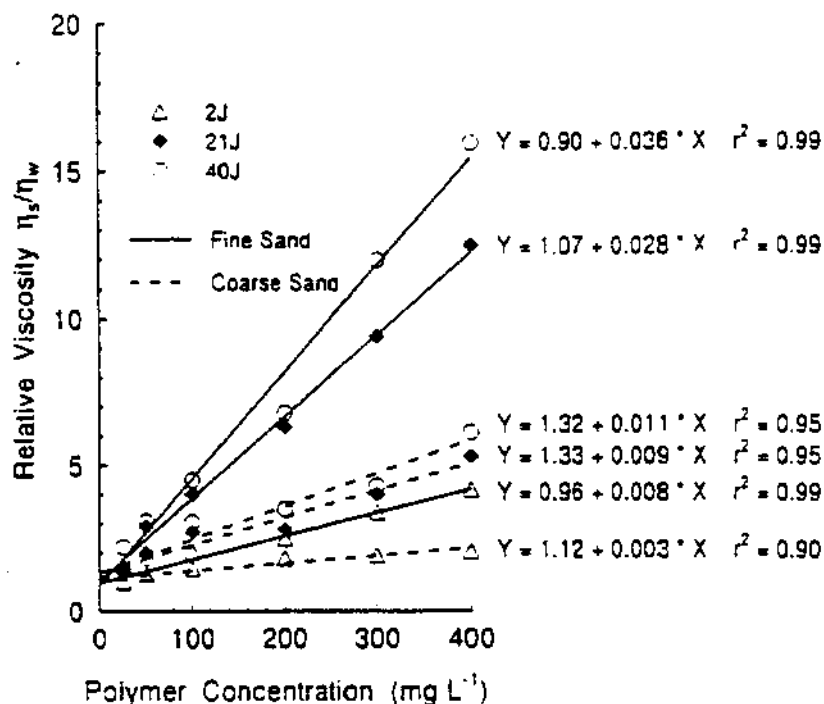


Table 1. Hydraulic conductivity (cm/min) for various polymer solutions and particle size fractions.

Concentration mg/L	Particle size, mm		
	<0.5>0.25	<0.25>0.15	<0.15
— SOILFIX G1—			
0	1.75	0.85	0.24
2.5	1.57	0.72	0.22
5.0	1.08	0.48	0.15
10.0	0.88	0.40	0.14
— 21J—			
0	1.76	0.86	0.23
2.5	1.43	0.68	0.24
5.0	1.26	0.58	0.22
10.0	1.13	0.51	0.22

References

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- Malik, M. and J. Letey. 1992. Pore-size-dependent apparent viscosity for organic solutes in saturated porous media. *Soil Sci. Soc. Am. J.* 56:1032-1035.